

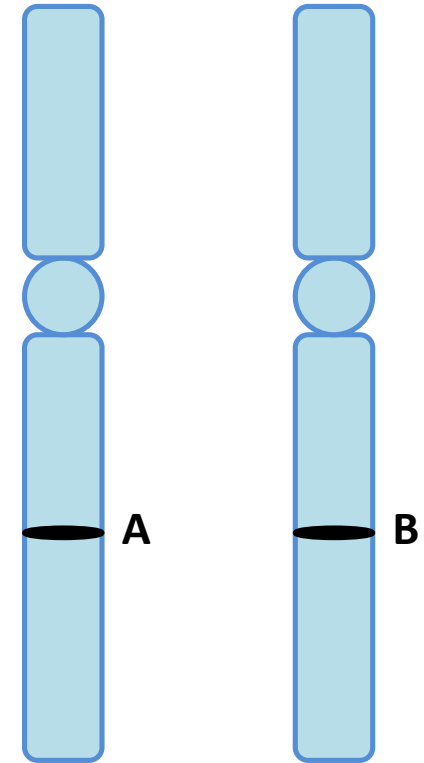
Linkage and crossing over

1. Introduction to linkage
2. Morgan's work
3. Difference between homologous and non homologous chromosomes
4. Difference between linked genes and unlinked genes
5. Comparison between complete and incomplete linkage
6. Parental and recombinant types
7. Crossing over
8. Cytological basis of crossing over
9. Cis and trans configuration of linked genes

Introduction

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- 2 genes (**A** and **B**):
 - Responsible for different traits of plant
 - Located on 2 different chromosomes (non-homologous)
 - Each gene has:
 - Two alternative forms (i.e. for Gene **A** there are 2 alleles= **A** and **a** ; for Gene **B** there are 2 alleles= **B** and **b**)
 - These genes will independently assort to give F1 generation of genotype **AaBb**
 - The F1 generation of selfing produce 4 types of gametes equally (i.e. **AB**, **Ab**, **ab**, **ab**)



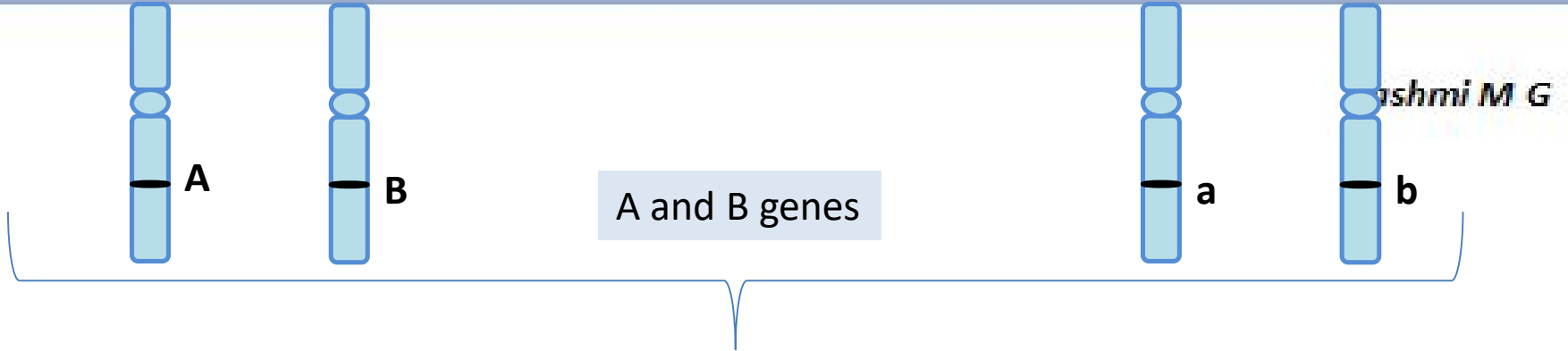
2 genes **A** and **B** located on Non-homologous chromosomes

Morgan's work

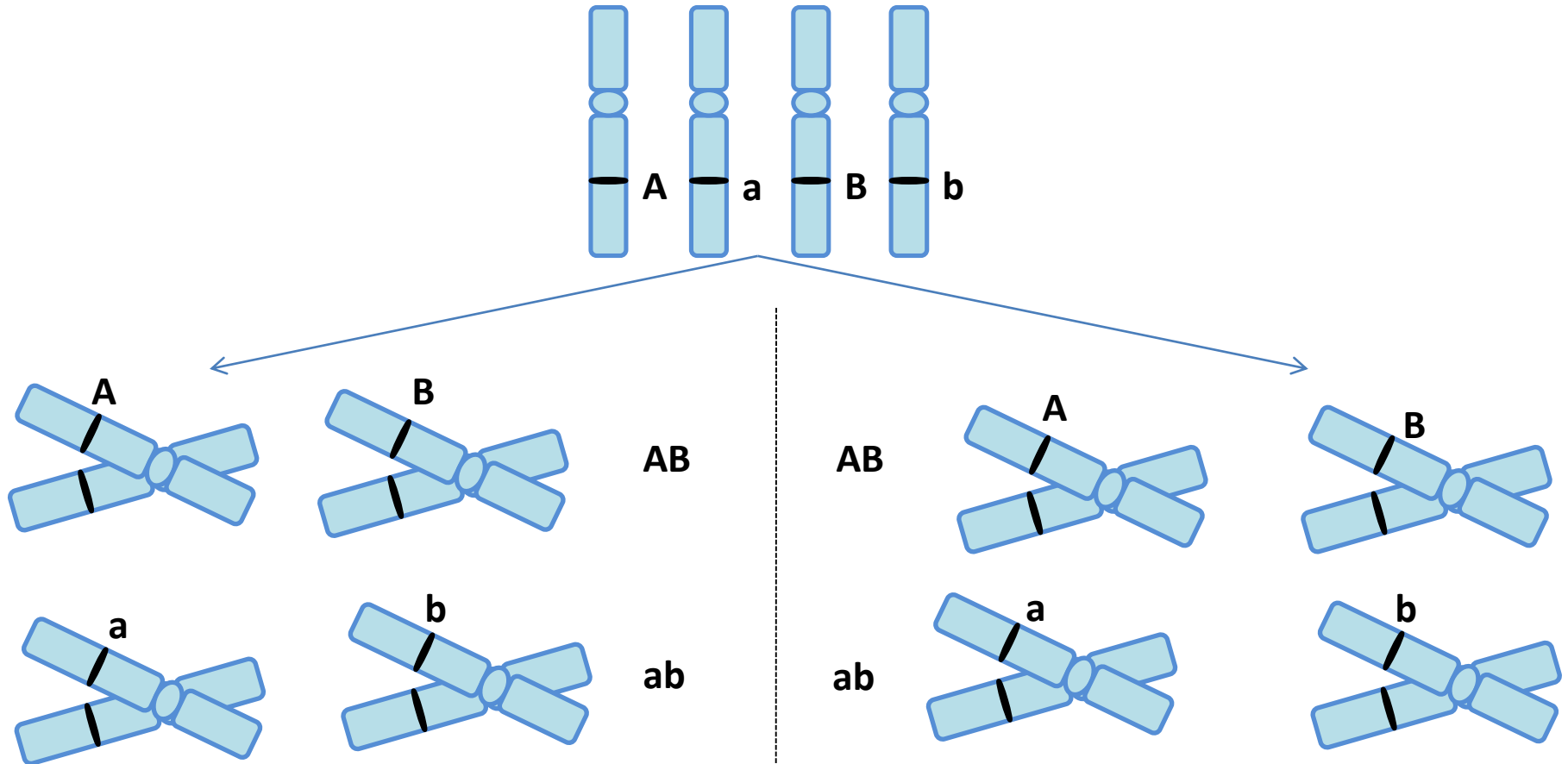
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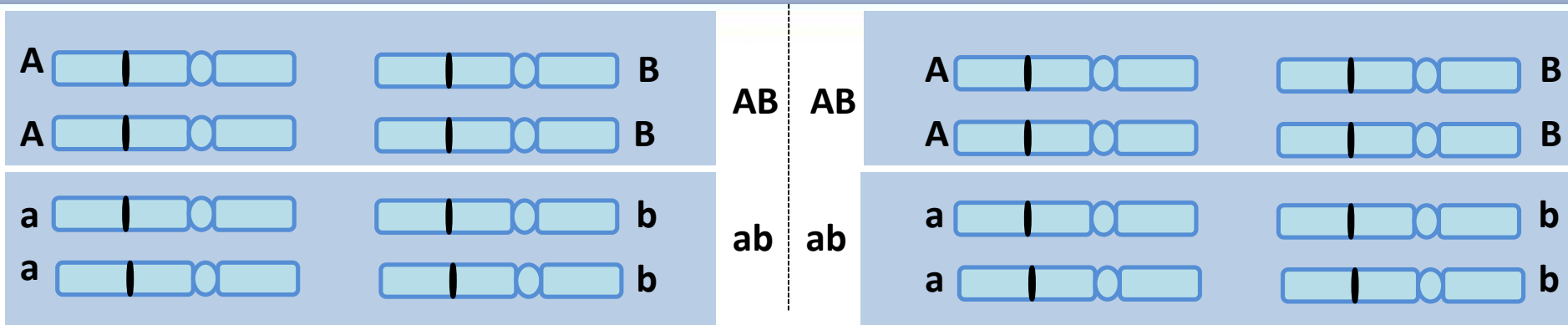
- It was Morgan who first discovered the phenomenon of **Linkage**
- He crossed yellow bodies with white eyes females with wild type gray bodies and red males *Drosophila*
 - F1 females were wild type
 - F1 Males expressed both mutant traits
- In F2 generation,
 - 98.7% of total offsprings showed the parental phenotype yellow bodied with white eyed flies and gray bodied with red flies
 - The remaining 1.3% of flies were either yellow bodied with red eyes or gray bodied with white eyes
- He proposed that,
 - 1.3% flies with recombinant feature developed as a result of separation of genes
- He postulated,
 - The separation of linked genes occurs due to formation of chiasmata which represent the point of genetic exchange
 - The term crossing over to describe the physical exchange leading to recombination
 - Two genes located relatively close to each other along a chromosome are less likely to have chiasmata between them as compared to the two genes which are farther apart on the chromosome



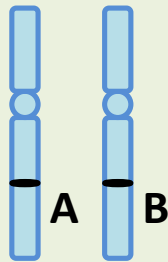


Independently assort and produce F 1 generation **AaBb**

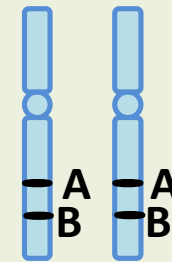




It produces gametes like **AB, Ab, aB, ab** equally



2 genes **A** and **B** located on Non-homologous chromosomes =
Unlinked genes



2 genes **A** and **B** located on same chromosomes = **Linked genes**

- But 2 genes of two different traits not always present on two chromosomes (non-homologous)
- 2 / more genes- Reside on same chromosomes is said to be linked
- These genes may be linked together on autosomal chromosomes or sex chromosomes
- **Linked genes**= genes on same chromosome
- Transmission pattern of these linked genes= **Linkage**

- A and B genes- on same chromosome
- So, In **Dihybrid** cross, **AABB** X **aabb**
- **Segregation** happens in a way,
- Genes tend to remain together
- Do not exhibit independent assortment
- Gametes formed by F1 progeny (AaBb) have 2 possibilities:
 - All gametes are of parental type
 - No recombination
 - Gametes of both parental type and recombination type
 - Recombination happened

Complete linkage

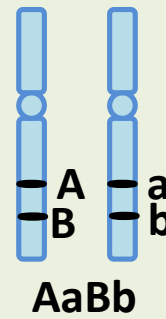
Incomplete linkage

Transmission pattern of linked genes= **Linkage**

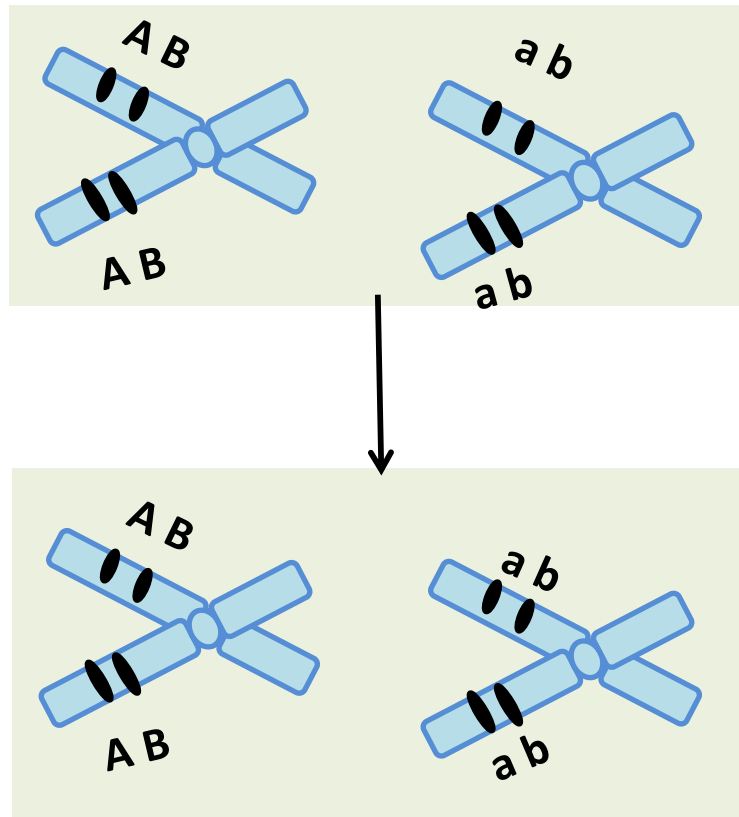
- 0 % recombinants
- Genes linked closely
- Shows parental type (genotype)
- No crossing over

- 0-5% recombinants
- Genes are linked but not in strong contact
- Shows both parental and recombinant types (genotypes)
- Crossing over occurs

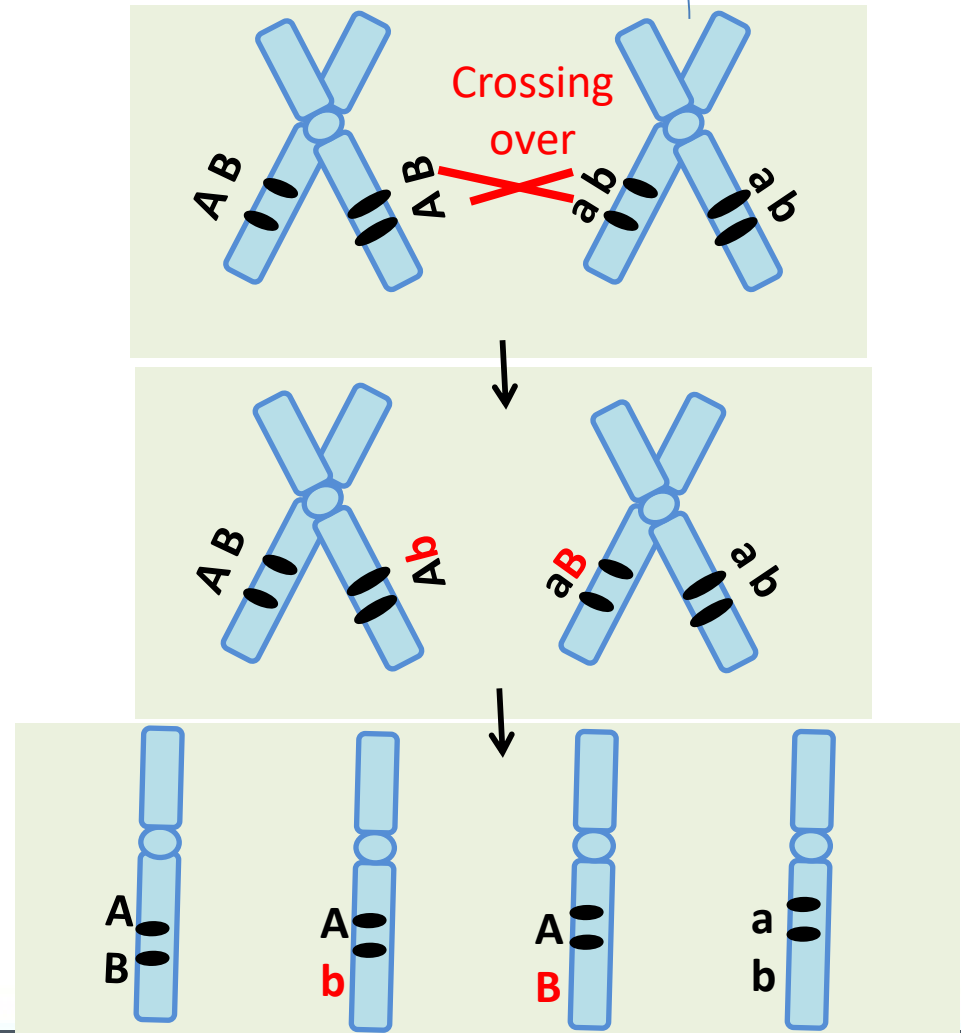
Note: A and B genes are linked together



Complete linkage



Incomplete linkage



Therefore recombinants are produced by 2 different cellular processes:

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1. Independent assortment

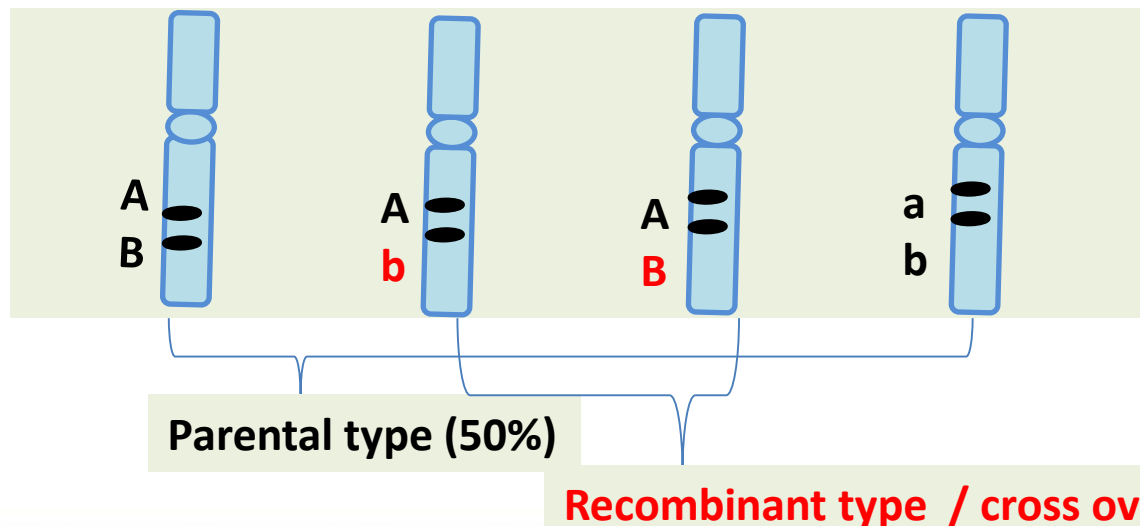
2. Crossing over

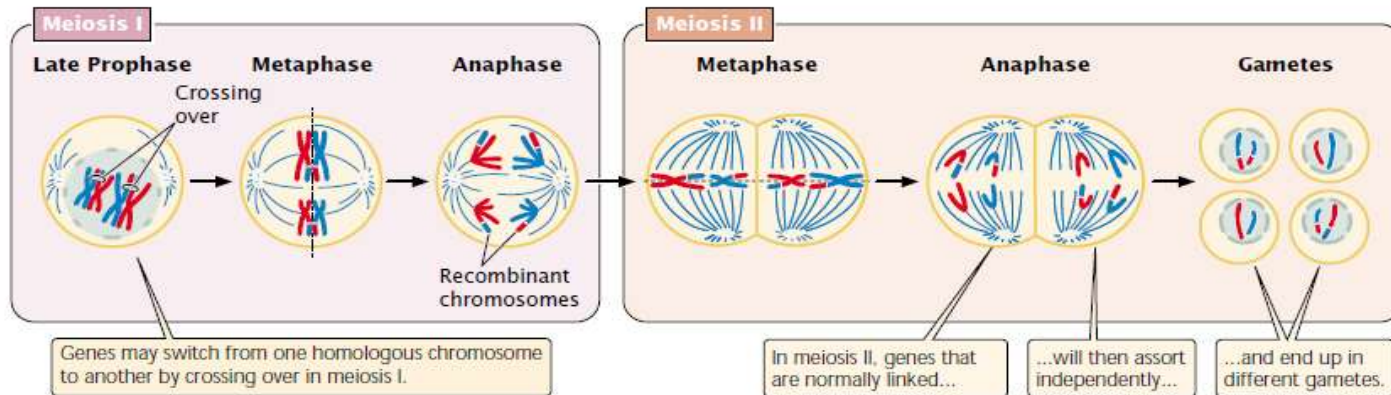
Independent assortment: It always produces 50 %recombinants

Crossing over:

- Also produces recombinants
- Does not occur between two specific genes in all meiosis
- But when occur, half of the products of that meiosis are recombinants
- Meiosis+ no crossing over
- Between genes
- Genes with percent recombination less than 50% are present in same chromosomes (**Linked genes**)
- Genes with percent recombination equal to 50% either are in non-homologous chromosomes or are located far apart on single chromosomes(**Unlinked genes**)

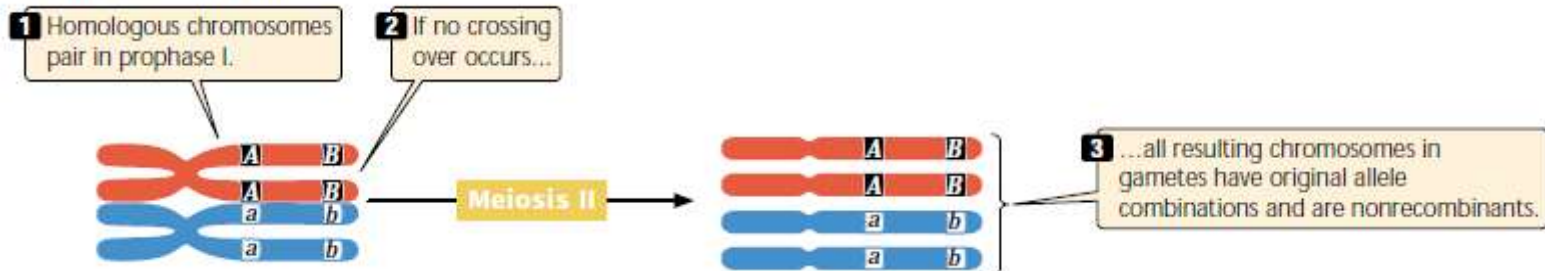
Produce only parental genotype for this genes



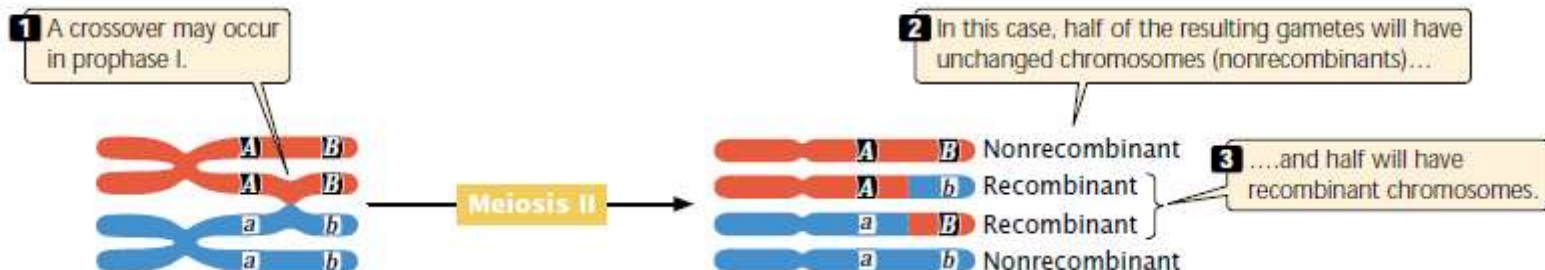


7.4 Crossing over takes place in meiosis and is responsible for recombination.

(a) No crossing over



(b) Crossing over



7.6 Crossing over produces half nonrecombinant gametes and half recombinant gametes.

Cytological basis of crossing over

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During meiosis, (Prophase I stage is generally subdivided into 5 stages i.e.

1. Leptotene- Bouquet stage
2. Zygotene- Synapsis, intimate pairing
3. Pachytene- Crossing over
4. Diplotene- Chiasmata appearance
5. Diakinesis- Proceeding to metaphase I

Especially in **Pachytene stage**, As soon as homologous chromosome (Pairing) is done- **Synapsis (intimate pairing)**

The cell may remain for days- A large **recombination nodule** (Large protein complexes, contain **Rad51**) appears at intervals on **synaptonemal complex** which mediates **Crossing over**

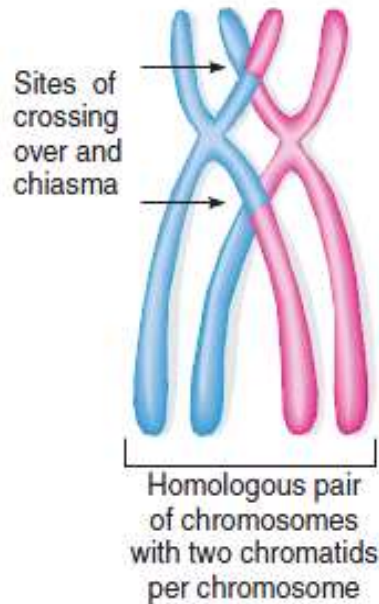
It leads to recombination of genes present on 2 homologous chromosomes

Many regions along the length of chromosome pair where crossing over frequencies are higher/ lower.

- Region of higher crossing over frequencies= **Hotspots**
- Region of lower crossing over frequencies= **Cold spots**

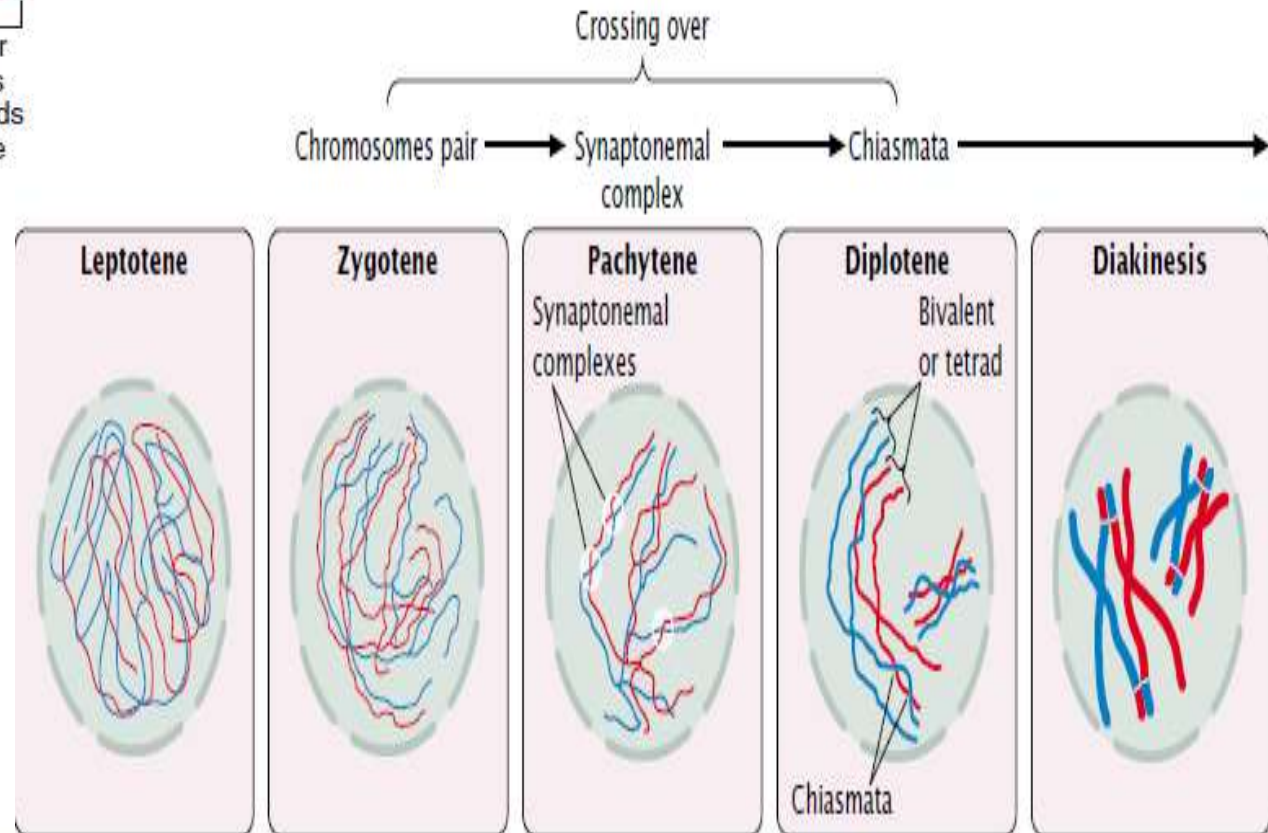
Appearance of chiasmata, the visible evidence of crossing-over, in diplonema.

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In, **Diplotene**,

- Desynapsis begins
- 2 homologous chromosomes in bivalent to pull away from each other
- Each bivalent remains joined by one/more **chiasmata**-represents sites where crossing over has occurred

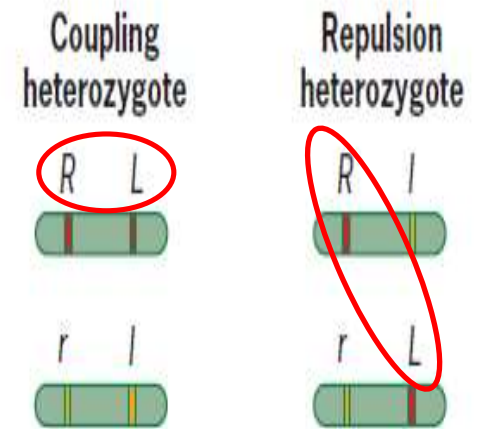


Source: Benjamin A Pierce, Genetics, A conceptual approach, Page no. 32
Peter J Russell, iGenetics A molecular approach, 3rd edition, Page no. 335

Cis and Trans configuration

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- Doubly heterozygous genotypes can be in two different configurations
- When 2 linked genes on each chromosome are of the same type (i.e. both dominant, AB or both recessive, ab), the arrangement is called-coupling/ cis
- When 2 linked genes on each chromosome are of different types (i.e. one dominant and one recessive allele, aB or Ab), the arrangement is called-repulsion/trans
 - In **cis configuration**, chromosome carrying allele combination either **AB** or **ab**- **Parental combination**
 - In **cis configuration**, chromosome carrying allele combination either **Ab** or **aB**- **Recombinant combination**
 - In **trans configuration**, chromosome carrying allele combination either **Ab** or **aB**- **Parental combination**
 - In **cis configuration**, chromosome carrying allele combination either **AB** or **ab**- **recombinant combination**



■ **FIGURE 7.5** Coupling and repulsion linkage phases in double heterozygotes.

Source: Snusted, Simmons (2012), Principles of genetics, John Wiley & Sons, Inc, Sixth edition, Page no. 138